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## STRUCTURED PACKING AND ELEMENT THEREFOR

The present invention relates to structured packing employed for fluid contacting systems such as a distillate tower or single or multiphase mixers and may be made catalytic for catalytic distillation.

Commercially, distillation is normally practiced as a multistage, counter current gas and liquid operation in a tower containing a packing device to facilitate the gas-liquid contacting that is necessary for both mass and heat transfer. Since multiple equilibrium stages exist in a tower, the compositions of the vapor and the liquid change throughout the tower length. The desired products can be removed as either liquid or vapor at an optimum location in the tower.

The more efficient the mass transfer device, the shorter the tower to achieve the same number of equilibrium stages. The mass transfer devices typically are separated trays which allow vapor to pass upwards through a small height of liquid or continuous packings which contain surfaces for gas-liquid contacting. The

ability to approach vapor-liquid equilibrium is either designated by a fractional "tray efficiency" or a "Height Equivalent to a Theoretical Plate" (HETP) for a continuous packing. The lower the HETP, the more efficient the packing. The advantage of structured packings are high efficiency coupled with low vapor pressure drop. Low pressure drops are desired because of the increased cost to force gases upwardly in the tower to overcome high pressure differentials, if present.

Examples of catalytic distribution structures are disclosed in US Pat. Nos. 4,731,229 to Sperandio, 5,523,062 to Hearn, 5,189,001 to Johnson, and 5,431,890 to Crossland et al. For example, the '229 patent discloses reactor packing elements comprising alternating fluted and unfluted parts with troughs that are inclined relative to the vertical. Apertures are provided in the parts to provide reagent communication flowing through the packing. The troughs are inclined relative to the vertical to ensure optimum fluid contact and to provide liquid holdup, vertical troughs permitting undesirable minimum liquid holdup, i.e., excessive liquid flow.

Catalytic distillation combines the separation (distillation) unit operation with chemical reaction by placing a catalyst inside a distillation column. Since most reaction rates are composition dependent, it is possible to locate the catalyst in an optimal position.

Also, in an equilibrium limited chemical reaction, it is possible to remove the product (by distillation) and drive the reaction forward. Most importantly, the use of catalytic distillation allows the use of fewer pieces of equipment. Thus, a prior two vessel reactor and distillation tower arrangement may now be combined into a single structure. US Pat. No. 5,321,163 discloses a catalytic distillation system.

The present invention is directed to improved packing for promoting contact between fluids; e.g., liquid-liquid or gas-liquid contact which may be used for a variety of purposes including conventional distillation and catalytic distillation.

In accordance with one aspect of the present invention, there is provided a porous structured packing to promote liquid-liquid contact and/or gas-liquid contact in which the average pore openings of the porous material forming the packing does not exceed about fifty microns and wherein the packing is provided with turbulence generators, such as baffles or tabs, which are spaced over the structured packing such that essentially over the entire surface of the packing there is flow of liquid through the pore openings in the packing.

The porous packing is preferably formed from a wire mesh or screen.

In a preferred embodiment, the packing is also provided with additional openings to promote bulk mixing.

In a particularly preferred embodiment, a wire mesh or screen which is a micromesh is used as the porous packing. A three-dimensional network or mesh formed of metal fibers or wires, with such fibers or wires generally having a diameter of at least 1 micron with the fibers having a diameter which generally does not exceed 25 microns, although smaller or larger diameters may be employed. The network may be of the type described in U.S. Patent Nos. 5,304,330; 5,080,962; 5,102,745; or 5,096,663. The three-dimensional network of materials may be one which is comprised of fibers, and may be a metal felt or the like, a metal fiber filter or paper and the like, or may be a porous metal composite. The compacted wires or fibers define a three-dimensional network of material which has a thickness thereto. In general, the thickness of the three-dimensional network of material is at least 5 microns, and generally does not exceed 10mm. In general, the thickness of the network is at least 50 microns and does not exceed 2 mm.

The three-dimensional network may be coated or uncoated and such three-dimensional network may have particles entrapped or contained therein. The network may have different pore sizes over the thickness thereof

and may be laminated and/or comprised of the same materials and/or may have multi-layers.

It is to be understood that the mesh may be comprised of one type of fiber or may be comprised of two or more different fibers or the mesh may have a single diameter or may have different diameters. The mesh is preferably formed of a metal, however, other materials may be employed such as a ceramic. As representative examples of such metals, there may be mentioned Nickel, various stainless Steels; e.g., 304, 310, and 316, Hastelloy, Fe-Cr alloys, etc.

The mesh can retain particles or fibers in the interstices thereof and the particles or fibers may contain a catalytic function.

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The structured packing may or may not include a catalyst. The catalyst, if used, may be coated on the fibers forming the packing and/or supported or unsupported catalyst may be entrained in the mesh openings.

Although it has been proposed to fabricate packings from porous materials such as a micromesh structure, Applicants have found that in order to efficiently use such porous materials as packings, it is necessary to provide turbulence generators which are spaced over the packing structure in order to provide for efficient flow of liquid through pores in the packing.

In a preferred embodiment, in addition to the turbulence generators, the packing is provided with additional openings.

In general, the size of the additional openings is 0.5 mm, preferably at least 1.0 mm in diameter (based on a circular opening). If the holes or openings are not circular, then such holes are sized in a manner such that at the minimum the area of such openings is essentially the same as the minimum area of a circular opening having such a diameter.

In each of the embodiments described with reference to the drawings, the holes formed in the packing structure (in addition to the holes or pores inherently present in the mesh material from which the packing is formed) in combination with turbulence generators (for example, in the form of tabs or baffles) function to provide for improved flow of fluid through the pores of the packing and improved bulk mixing for essentially over the entire surface of the packing.

Applicant has found that, in the absence of turbulence generators, the packing functions in a less efficient manner in that fluid does not effectively flow through the pores of the packing.

In accordance with the invention, the turbulence generators and the holes formed in the packing structure (in addition to the holes or pores inherently present in



the mesh material from which the packing is formed) the function to provide an optimization of flow through the pores and improved bulk mixing over the length of the packing, while still allowing sufficient surface area for gas/liquid mass transfer and/or catalytic reaction.

Such additional holes and turbulence generators, are spaced over the packing to achieve such optimization. This can be done either by experimentation or more preferably by a model of the process that describes the structure (including, geometry, thickness, porosity and fiber diameter) and the gas and liquid flow patterns through the structure, including any heat effects created by included reactions. One example of such a model would use the procedure known as computational fluid dynamics.

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The holes or openings which are added to the porous packing generally comprise at least about 3% and preferably at least 10% of the packing surface. In most cases, the additional openings do not comprise more than 20% of the surface and preferably no more than 25% of the surface.

The tabs or baffles function to break up bubbles and also create bubbles behind the tab or baffle.

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Furthermore, the tabs or baffles function to increase liquid mass transfer by inducing turbulence and creating bubbles.

The invention will be further described with respect to representative embodiments of packing structures formed from a mesh material; however, such structures are by way of illustration in that the present invention is applicable to other structures and designs. Thus, the present invention, in part, is based on the inventor's discovery that highly porous mesh material, when used as packing, even though such material has a high-void volume; for example, greater than 70% and in many cases greater than 90% fluid does not effectively flow through the pores of the packing and that fluid flow through such pores can be improved by providing turbulence generators. Thus, in accordance with the present invention, turbulence generators, are provided with the number, size and spacing thereof being selected to improve liquid flow through the pores of the mesh structure over the surface of the mesh structure.

In a preferred embodiment, the packing is also provided with additional openings. The size and spacing of the additional holes or openings, preferably in combination with turbulence generators, are selected to obtain a desired bulk mixing and pressure drop through the mesh of the structured packing.

In the following illustrative embodiments, the additional openings are formed by creating tabs which function as turbulence generators, which tabs are preferred in that they provide for the generation of turbulence and also have further advantages as hereinafter described. However, the openings can be created in accordance with the invention without creating tabs. In addition turbulence generators can be provided separate and apart from the openings. Such turbulence generators can be in the form of baffles or tabs independent of additional openings or for example by providing bosses or dimples or corrugations on the packing.

In the following embodiments, the mesh structure of the structured packing includes openings in addition to those created by forming the tabs. Such additional openings may or may not be required depending on the shape of the packing and the conditions contemplated for the packing structure.

IN THE DRAWING:

FIGURE 1 is an isometric view of a packing structure according to one embodiment of the present invention;

FIGURE 2a is a top plan view of one of the packing elements of Fig. 1;

FIGURE 2 is a front elevation view of the packing element of Fig. 2a taken along lines 2-2;

FIGURE 3 is a top plan view of the structure of Fig. 1;

FIGURE 3a is a more detailed view of a portion of the structure of Fig. 3;

FIGURE 4 is a front elevation view of a blank forming a packing element of the structure of Figure 1;

FIGURE 5 is an isometric view of a packing element of a second embodiment of the present invention;

FIGURE 6a is a top plan view of the element of Fig. 5;

FIGURE 6 is a front elevation view of the element of Fig. 6a taken along lines 6-6;

FIGURE 7 is a top plan view of a packing structure employing a plurality of elements of Figs. 5 and 6;

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FIGURE 8 is a more detailed plan view of a portion of the structure of Fig. 7;

FIGURE 9 is a front elevation view of the blank used to form the element of Fig. 5;

FIGURE 10 is a plan view of a portion of a packing structure according to a further embodiment of the present invention;

FIGURE 11 is a fragmentary side elevation view of the embodiment of Fig. 10 taken along lines 11-11; and

FIGURE 12 is an isometric view of the embodiment of Fig. 11.

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In Fig. 1, structured packing 2 comprises an array of identical packing elements 4, 6, 8 and 10 which are part of a larger array 3, Fig 3. While nine elements are shown in Fig. 3, this is by way of illustration, as in practice more or fewer elements may be used according to a given implementation. Also, the elements are shown in a square array. This configuration is also by way of illustration. In practice, the array may also be rectangular, circular or any other desired shape in plan view, comparable to the view of Fig. 3.

If the array is circular in transverse section, the elements necessarily are not identical in overall transverse width from left to right in Fig. 3. The elements are housed in an outer tower housing 12 (shown in phantom) which in this case is square in transverse section. Other housings (not shown) may be rectangular or circular in transverse section. The elements conform to the housing 12 interior shape to fill the interior volume.

Each element 4, 6, 8 and 10 is formed from an identical substrate blank 14, Fig. 4, of preferably composite porous metallic fibers as described in the introductory portion. The material is preferably formed from the material as described in the US patents noted in the introductory portion and which are incorporated by reference herein.

The material of the elements may also be solid sheet metal or other materials as known to those of skill in this art. The blank 14 is a fragment of and represents a portion of a larger complete blank forming each of the elements of Fig. 3. The complete blank (not shown) appears as shown for the partial blank 14 with an identical repetition of the illustrated pattern extending to the right in the Figure (and according to a given implementation, may extend further vertically from the top to bottom of the figure).

In Fig. 4, the substrate blank 14 includes a plurality of through cuts represented by solid lines. Fold lines are illustrated by broken lines 16, 18, 20, 60 and so on. A first row 22 of identical tabs 24 and identical through holes 26 are formed with a tab 24 and hole 26 disposed between each of alternating pairs of adjacent fold lines, such as lines 16 and 18, 20 and 21 and so on. Tabs 24 eventually form vortex generators as will be described below herein. The holes 26 are adjacent the tip region of the tabs 24 and are located on a channel forming fold line at which the inclined edge 30 emanates. Reference numerals with primes and multiple primes in the figures represent identical parts.

Each tab 24 has a first edge 28 coextensive with a channel forming fold line, such as line 18. The tab 24 has a second edge 30 which emanates at a second channel

fold line such as fold line 16 inclined to the fold lines 16 and 18 terminating at a distal end segment tip 32. The edges 28 and 30 terminate at one end at tab fold line 60 along plane 33. The tip 32 has an edge that is coextensive with edge 28 both of which edges are straight and lie on a channel fold line, such as line 18.

The edges 28 and 30 both emanate from a common transverse plane 33 as do all of the edges of the tabs 24 of row 22. The tip 32, which is optional, preferably is square or rectangular for the purpose to be described, but may be other shapes as well according to a given implementation. Holes 26 are slightly larger than the tip 32 so as to permit a tip 32 of a tab 24 to pass therethrough in a manner to be explained. All of the tabs 24 and holes of row 22 are aligned parallel to plane 33.

Additional rows 27 and 29 of tabs 24 and holes 26 are aligned parallel to row 22 and are aligned in the same column such as column 34 between a given set of fold lines such as lines 16 and 18. The tabs 24 and holes 26 between fold lines 16 and 18 are aligned in column 34. The blank 14 as shown has alternating columns 36, 38 and so on corresponding to column 34 of tabs 24 and holes 26 which are aligned in the respective rows 27 and 29. More or fewer such rows and columns may be provided according to a given implementation.

The rows 22, 27 and 29 alternate with rows 40, 42 and 44 of tabs 24 and holes 26. The tabs 24 and holes 26 of rows 40, 42 and 44 are in the alternate columns 46, 48, 50 and so on. Consequently, the blank 14 has a plurality of rows and columns of the tabs 24 and holes 26 with the tabs of a given set of columns and rows alternating in vertical and horizontal position with the tabs and holes of the remaining columns and rows as shown.

In Figs. 2 and 2a, the element 4, as are all of the elements, is formed by bending the blank substrate material along the fold lines 16, 18, 20, 21 and so on (Fig. 4) in alternating opposite directions. This forms the blank 14 into a channelized quasi-corrugated structure. The structure has identical preferably square in plan view channels 54, 56, 58 and so on. These channels face in alternating opposite directions 59. Thus channels 54, 58 and so on face toward the bottom of the figure, directions 59 and channels 56, 61, 63 and so on face in the opposite direction toward the top of the figure.

In Fig. 3a, representative element 62 has channels 64, 66, 68, 70 each having a respective intermediate connecting wall 72, 74, 76 and 78 and so on lying in planes extending from left to right in the figure spaced in a normal direction. Channel 66 has lateral side walls



80 and 82 and channel 68 has lateral side walls 82 and 84 with wall 82 being in common for channels 66 and 68. The element 62 has further identical channels as seen in Fig. 3. All of the elements of packing 2 are constructed similarly with identical channels.

Prior to forming the channels or at the same time, the tabs 24, Fig. 4, are bent to extend from the plane of the blank 14 to form vortex generators at collinear fold lines 60 lying on plane 33.

The tabs 24 in row 22 are bent out of the plane of the figure in opposite directions in alternate columns 34, 36, 38 and so on. Thus the tabs of columns 34, 38, and 45 are bent in the same direction, e.g., out of the drawing plane toward the viewer. The tabs in columns 36 and 41 are bent in the opposite direction out of the plane of the figure away from the viewer. The same bending sequence is provided the tabs of rows 27 and 29 which are in the same columns as the tabs of row 22 so that the tabs of a given column are all bent in parallel directions.

The tabs 24' of the next row 40 in the adjacent alternate columns 46, 48, 50 and so on are all bent parallel in the same direction at corresponding collinear fold lines 86 parallel to plane 33 toward the viewer. They are also parallel to the tabs of columns 34, 38 and so on.

The tabs 24" of the next row 27 are bent at their respective fold lines in the same direction as the tabs 24' in row 27, e.g., toward the viewer out of the plane of the drawing. These tabs are parallel to the tabs of row 40.

The tabs 24"' of the row 42 are bent at their fold lines 88 in a direction opposite to the bend of the tabs of rows 27 and 40, e.g., in a direction out of the plane of the drawing away from the viewer. These tabs are parallel and bent in the same direction as the tabs in columns 36 and 41. The tabs of row 29 are bent in the same direction as the tabs of rows 22 and 27 in the same columns, repeating such bends. The tabs of row 44 are bent the same as the tabs of rows 42 and 40 toward the viewer.

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In Figs. 1 and 2, element 4 has a set of tabs 24<sub>1</sub>, 24<sub>1</sub>', 24<sub>1</sub>", 24<sub>1</sub>'", 21 and 23 in channel 54. The tabs 24<sub>1</sub>, 24<sub>1</sub>", and 21 all extend in the same direction, for example, from channel 54 connecting wall 90 into the channel 54. The tabs 24<sub>1</sub>', and 23 extend from the same lateral side wall, e.g., side wall 92. The tab 24<sub>1</sub>'", however, extends into channel 54 from the opposite lateral side wall 94. The tabs in plan view along the channel 54 length, from the top of the figure to the bottom, in Figs. 1 and 2, interrupt the vertical channels and thus form a solely tortuous generally vertical path

for fluids. No open continuous vertical linear fluid path is available along the channel lengths for any of the channels.

The tabs in the next opposite facing channel 56 are in mirror image orientation to the tabs of channel 54 as best seen in Fig. 2.

The tortuous blocking interruption of the vertical linear path by the tabs is best seen in Fig. 3a. Representative element 62 channel 66 has an uppermost tab  $24_2$ , a next lower tab  $24_2'$  and then a still next lower tab  $24_2''$  and so on. As shown, a portion of each of the tabs overlies a portion of the other tabs in the channel. In the plan view the channel 66 is totally blocked by the tabs, as are all of the channels, in the vertical direction normal to the plane of the figure. Thus no linear vertical fluid path is present along the length of the channel 66 (or channels 54, 56, 58 and so on in Fig. 2). Also, each tab in a given channel has one edge thereof adjacent to and abutting either a lateral side wall or a connecting wall.

The holes 26 each receive a tip 32 of a corresponding tab. For example, in Fig. 3a, a tip  $32_2$  of tab  $24_2$  extends through a hole 26 into adjacent channel 96 of an adjacent element 102. A tip  $32_2'$  of tab  $24_2'$  extends into adjacent channel 98 of element 62. A tip  $32_2''$  of tab  $24_2''$  extends into adjacent channel 100 of

element 62. The tab tips thus extend through the corresponding holes 26 of the channel thereof into a next adjacent channel for all of the tabs.

The tabs extending from an intermediate connecting wall, such as tab 24<sub>2</sub>, Fig. 3a, attached to wall 74 of element 62, extend toward and pass through the hole 26 of the connecting wall of the adjacent packing element, such as wall 97 of element 102. However, none of the tabs of element 102 extend into or toward the channels of the element 62. Thus, the tabs of each element are employed for substantially cooperating with only the channels of that element to provide the desired tortuous fluid paths. The tabs of each element are substantially independent of the channels of the adjacent elements, notwithstanding that the tips 32 of the connecting wall tabs cooperate as described with the connecting walls and channels of the adjacent elements.

The tabs 24 and tips 32 are not bent away from the plane of the blank 14, Fig. 4 for those walls of the channels next adjacent to the housing, which walls abut the housing 12. Thus the tabs at the edges of the structure array 3, Fig. 3, do not extend beyond the structure so as to not interfere with the housing 12 interior walls. In the same manner, the tabs at the edge surfaces of the structure 3 are not bent beyond the plane

of these surfaces as shown in Figure 3. Holes 26 in these edge surfaces are also not necessary.

The tips 32 and holes 26 are employed to provide drip flow of liquid to opposite sides of the respective channel walls to enhance fluid contact throughout the packing structure. The holes 26 also provide fluid communication among the channels in directions transverse the vertical axis of the structure array 3. Of course, the openings in the structured elements sheet material formed by bending the tabs out of the plane of the sheet material provide major fluid communication between the channels in a transverse direction. These openings and openings 26 are formed in all four walls of each interior channel.

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The elements of structure array 3, Fig. 3, such as elements 4, 6, 8, 10 and so on, are preferably secured together by spot welding the corners of the channels at the upper and bottom array 3 ends. The welding is optional as the elements may be dimensioned to fit closely into the tower housing 12 (Fig. 3) and held in place to the housing by friction or by other means (not shown) such as fasteners or the like. The elements may also be secured together first by any convenient fastening devices or bonding medium.

It should be understood that the number of tabs in a channel and their relative orientation is given by way of

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example. For example, only one tab, such as tab 24<sub>1</sub>' in channel 54 extends from the lateral side wall 94 into channel 54. In practice, more than one tab would extend from each side wall into each channel. Also, the sequence of tab orientation, e.g., which tabs extend from a given wall in a vertical sequence, is also by way of example, as other orientations may be used according to a given need.

Further, the vertical length of the elements and the packing array channels of the array 3 in practice may vary from that shown. The channel lengths are determined by the factors involved for a given implementation as determined by the type of fluids, volumes thereof, flow rates, viscosities and other related parameters required to perform the desired process.

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In operation, the structured packing 2, Fig. 1, may be used in a distillation process, with or without a catalyst or in a single stage or two stage mixing process. In addition, the packing may be used for liquid-vapor contact providing high specific surface area (area per unit volume), relatively uniform distribution of vapor and liquid throughout the column, and uniform wetting of the involved surfaces. The preferred microporous substrate material forming the structure provides enhanced wetting of the packing surface through its surface texture for catalytic applications. In the

alternative, the catalyst is attached to the solid sheet material forming the structure.

The preferred micro mesh material provided by the sintered fiber sheet material of the packing elements provides relatively high catalyst surface area with optimum access to the catalyst by the fluids. The fibers are either coated with the catalyst or support the catalyst particles trapped in the porous network of the sheet material. Where relatively rapid chemical reactions are desired, utilization of the internal surface area of the porous material is dependent upon the rate of transport of the reactants to these surfaces. The mass transport is higher in the case of driven forced flow (convection) than by mere concentration of gradients (diffusion). The structure therefore provides optimum cross flow of the fluids with low pressure drop thereacross.

To maximize capacity, the pressure drop is maintained relatively low. This is provided by relatively high void space per unit column volume, low friction (good aerodynamic characteristics) and prevention of undesirable stagnant liquid pockets.

In a catalytic distillation process, a catalyst is secured to the sheet material forming the elements as discussed above. The catalyst may impregnate the voids of the element sheet material or may be external thereto.

In a distillation process, liquid permeates downward through the packing while gas to be mixed with the liquid rises.

The rising gas exhibits turbulence due to the presence of the tabs which act as vortex generators and due to the openings between the channels. The gas flows into the different channels via the holes 26 and via the openings formed by the bending of the tabs 24 from the plane of the sheet material substrate. As the gas rises it can only traverse a tortuous vertical path in each channel as no direct vertical linear path is available due to overlapping portions of the vortex generating tabs. This enhances contact of the gas and liquid (two phase) or multiple gases or liquids in a single phase.

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It can be shown that the vertical channel orientation provides improved low pressure drop with optimum liquid hold up. The resulting turbulence generated by the vortex generators contributes to the liquid hold up. Vertical channels have the advantage of low pressure drop, but normally also exhibit poor mixing and gas-liquid mass transfer. However, the vortex generators and openings between elements of the structure of the present invention allow the use of essentially straight vertical channels. The resulting structured packing of the present invention exhibits the low pressure drop of vertical linear channels, and at the

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same time also exhibits superior mixing and mass transfer characteristics due to the tortuous fluid paths.

Also, the vortex generators tabs 24 serve as drip points for the liquid to distribute fluid from one side of a channel to the other. The tips 32 serve to enhance liquid dripping into adjacent channels and along the opposing walls of a channel. Also, the tips engage the corresponding channel sides to resist vibrations and provide further stability.

Liquid flows through the holes 26 to the adjacent channels and the liquid contacts the opposite side walls of a channel and flows down those walls also as it flows down the inclined tabs. The holes 26 provide pressure equalization and communication from one channel to the next and create a tortuous path for the fluids whether gas or liquid.

The preferably square or optionally rectangular shape of the vertically oriented channels provides more surface area as compared to prior art inclined corrugated triangular channels. The channels may also have various geometries, such as round, triangular, or other polygons in transverse section. For example, the channels transverse section may be hexagonal or other regular or irregular shapes according to a given implementation.

In a bubble regime, liquid is carried from channel to channel with bubbles, providing enhanced liquid

distribution. In this case, linked channels may be optional. Also, relatively smaller and more numerous vortex generators may also be employed. The tips 32, Figs. 1-4 also may act as vortex generators.

Vapor is distributed through the openings in the channel walls while liquid is distributed by flowing over the tabs into the adjacent channels. The tabs 24 also interrupt the liquid as it flows providing relatively constant liquid film renewal and therefore good mixing in the liquid phase. The tabs 24 prevent concentration of liquid in the corners of the channels by diversion of the liquid, i.e., minimizes gutter flow. Further, reorientation of the packing elements by 90° as done with angled channels is not necessary with vertical channels.

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The number of vortex generators can differ from top to bottom of the structure. Thus a greater number of vortex generators may be placed closer to the structure top for enhanced liquid distribution. Fewer vortex generators may be placed closer to the structure bottom to reduce overall pressure drop. Sandwiched designs may also be used. These designs comprise axially segmented packing elements performing different functions. For example, the mixing or liquid distribution can be provided at one packing segment and chemical reaction can be provided at a different axially disposed packing segment.

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An important aspect is that very little material of the substrate is lost since the tabs that are utilized in the structure also provide fluid cross communication openings in the channel sidewalls. The holes 26, which are optional, and are not essential, especially for relatively large pore substrate material, represent a minor loss of material which is relatively costly.

Further, a relative large amount of drip points are provided to maximize liquid-gas mass transfer and mixing. Optimum side wall pressures can be provided by selection of the side wall positions of the tabs, i.e., by having an edge adjacent to a channel side wall or by positioning the tabs in optimum relative vertical positions.

The vortex generators may of any shape, but preferably are triangular. They may be, for example, rectangular or round e.g., semicircular, according to a given implementation. They may also contain a trapezoidal segment as described. The vortex generators each contain a portion that substantially interrupts and redirects fluid flow in the axial vertical direction providing the desired vertically extending tortuous path.

The vortex generators provide turbulence to maximize two phase mass transfer or mixing of single phase fluids. By directing liquid into the middle of a channel, the vortex generators also maximize two-phase contact area in the vertical channels. The transverse openings between

channels made by the vortex generators also provide liquid and gas communication to various portions of each channel and adjacent channels.

By way of example, the channels in one embodiment may be 12 mm in transverse dimension in a square channel. The channels and packing vertical length may be 210 mm in that embodiment employing eight vortex generators in a channel. Smaller or larger channels, their length and the number of generators is determined according to a given implementation.

In Figs. 5-9, an alternate embodiment of a packing structure and element therefor is shown. In Figs. 5 and 6, element 104 comprises porous substrate material of the same porous metal fiber construction as the material of the elements of Fig. 1 and as described in the introductory portion. It should be understood that the porosity of the substrate is not illustrated in the Figures and that the drawings in relation to various dimensions is not to scale for purposes of illustration. The sheet material thickness and fiber diameters being in the order of microns as discussed above.

The element 104, which is a fragment of a larger element in the drawing, in practice extends both horizontally and vertically beyond what is shown, comprises a plurality of square in transverse section channels 106-110 and so on. The element 104 in use is

oriented with the channels vertical in a processing tower (not shown). A plurality of vortex generating triangular tabs 114-126 and so on are formed from the sheet material substrate and extend completely across the corresponding channel in which they are located. The tips of the tabs may abut or be closely spaced from the opposite channel lateral side wall or intermediate connecting wall as applicable.

In the case of the tabs extending from a connecting intermediate wall, these tabs abut or are closely spaced to the connecting intermediate wall of the next adjacent packing element as shown in Figs. 7 and 8 to be described. This is so that liquid drips along a tab onto that opposite channel side wall and then along that wall.

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The tab tips need only be sufficiently close to the opposite wall so that flowing liquid on that tab drips the liquid onto that wall.

The element 104 is formed from a substrate sheet material of preferably porous sintered metal fiber blank 126, Fig. 9. The blank 126 preferably comprises the same sintered porous fibrous material described above. The blank is a planar sheet wherein solid lines represent through cuts and dashed lines represent fold lines. Fold lines 128, 130, 132 and so on form the channels 106-110 when the substrate 134 is bent at right angles at the fold lines. Fold lines 136 are aligned in linear rows

normal to the channel fold lines 128 and so on in parallel planes such as plane 138. The tabs each correspond to and are bent at a fold line 136 out of the plane of the blank.

Each tab, e.g., tab 114, has a first edge 131 inclined to and emanating from a vertical fold line, e.g., line 128, and a horizontal fold line, e.g., line 136, and has its tip terminating at the next adjacent vertical fold line of that column, e.g., line 130. Each tab, e.g., tab 114, has a second edge which emanates from a horizontal fold line, e.g., line 136, and is vertically coextensive with the next adjacent fold line of that column, e.g., fold line 130.

The tabs are aligned in vertical columns 142, 144, 146, 147, 148, 150, 152 and 154 and so on and in horizontal rows 140, 141, 143, 145, 146 and 149 and so on. The tabs in adjacent rows, such as rows 140 and 145, are in alternate columns. The tabs in row 140 are in respective columns 142, 148 and the tabs in row 145 are in columns 144, 146 and so on. Alternate tabs in top row 140 are bent in the same direction. For example tabs, such as tabs 114, 114' and 114", in row 140 and located in columns 142, 150, and 154 are bent in the same direction toward the viewer out of the plane of the drawing. The columns 142, 150 and 154 form the respective connecting walls 142', 150' and 154', Fig. 5,

and the columns 148, 145 form the respective connecting walls 148', 145.

In Fig. 5, the tabs 114, 114' and 114" each extend parallel into the corresponding channel 106, 108 and 110 respectively from their corresponding channel connecting walls.

The other alternate tabs, Fig. 9, in row 140, e.g., tabs 121, 121' in respective columns 148 and 152, are bent in the opposite direction away from the viewer out of the plane of the drawing. These are connected to connecting walls 148' and 152', Fig. 5. These tabs are bent into the corresponding channels 107 and 109 which face in opposite directions as channels 106, 108 and 110 in which tabs 114, 114' and 114" extend.

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The tabs in alternate rows in each column, e.g., rows 141 and 143, are bent in the same direction and parallel to the tabs of row 140. That is, tab 116 is bent parallel to tab 114 and tab 122 in the next alternate column 148 is bent parallel to tab 121, the tabs in columns 142, 150 and 154 being bent in opposite directions as the tabs in columns 148, 145 and so on. This pattern of bends repeats for the remaining columns for the tabs in the rows 140, 141 and 143.

The tabs of row 145, tabs 115, 127 and so on, and row 147, tabs 118, 117 and 124 and so on, are all bent in parallel in the same direction from the plane of the

substrate material, i.e., toward the viewer out of the plane of the drawing figure, Fig. 9.

The tabs of row 147, e.g., tabs 118, 117, 124 and so on are bent in the same direction as the tabs 121, 122 and 123 of column 148 and the tabs of column 152. These are bent in a direction away from the viewer out of the plane of the drawing figure. While only one row of tabs, row 149 are bent in this opposite direction in the corresponding columns, more such tabs are preferably provided, e.g., by making the element 126 longer or rearranging the tab orientation of the other tabs in each channel.

In Fig. 5, tabs 114, 115, 116, 117 and 120 all are in channel 142'. Tab 118 is located in channel 150'.

Tab 115, 117 and 120 emanate from the same channel lateral side wall 156. Tab 117 emanates from the opposite side wall 158. The remaining tabs of channel 106 emanate from connecting wall 160. The above pattern of tabs repeats for each of the remaining channels, with the tabs 121, 122 and 123 emanating from the connecting wall 162 of opposite facing channel 107.

In Figs. 7 and 8, packing structure 164 comprises a plurality of elements 166, 168, 170 and so on identical to element 104 arranged in a square array. The array could be other shapes such as rectangular or circular according to a given need. In Fig. 8, the connecting



walls 172 of element 168 enclose the channels 174-175 and so on of element 170 and walls 173 of element 171 enclose channels 176 and 177. In this way all of the interior channels are enclosed by connecting walls of the next adjacent element. The elements of the structure 164 are attached to each other as described above for the embodiment of Fig. 1.

In Fig. 8, uppermost tab 178 (corresponding to tab 121, Figs. 6 and 6a, for example) of element 170 in channel 174 depends from connecting wall 180. Tab edge 131 extends diagonally across the channel 174 from corner to corner. tab edge 132 is next adjacent lateral side wall 183. The tab 178 tip 182 is next adjacent to the opposite connecting wall 172' of element 168.

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The next lower tab 184 (corresponding to tab 127, Fig. 6) depends from side wall 186. Its inclined edge 131' extends from lateral side wall 186 to wall 183. Its other edge 132' is next adjacent to connecting wall 180. Edges 132 and 132' may abut or be closely spaced to the adjacent corresponding wall for permitting liquid flowing on the tabs to flow onto that wall. The tab 184 tip 187 is at the corner junction of walls 180 and 183. Liquid flowing to the tip thus flows to that corner on the opposite side of the channel from wall 186. The edges 131 and 131' may overlies one another or slightly overlap the next adjacent tab body.

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The next lower tab, tab 188, depends from wall 183 and is beneath tab 184. Tab 188 has an inclined edge 131" extending overlying edge 131'. Tab 188 has the opposite edge 132" abutting or closely spaced to connecting wall 172' of element 168.

As a result, the tabs 178, 184 and 188 completely block the channel 174 in the vertical direction, providing a tortuous fluid path in the vertical direction. A gas flowing vertically upwardly in the channel 174 must flow past and about the inclined edges 131, 131' and 131" of the respective tabs. The remaining tabs in that channel provide a similar tortuous path for fluids attempting to flow in a vertical direction. No linear vertical path is provided for the fluids. The tabs serve as vortex generators maximizing mixing and contact of the flowing fluids. Liquids flowing downwardly flow along the channel sides and along the tabs and are distributed to the various opposite channel side walls.

The tabs by being bent from a plane sheet substrate, form large openings in the substrate. These openings form cross communicating paths for fluids to flow to the channels of the adjacent elements. This minimizes the pressure drop transversely the channels, and the vertical tortuous path minimizes the pressure drop in the vertical directions. Turbulence is created by the tabs in each

channel and in cooperation with the openings in the channel walls. The inclined tabs provide optimum liquid holdup as the liquid flows downwardly.

It will be appreciated that in place of triangular tabs, the tabs can be trapezoidal somewhat similar to the tabs of Fig. 1, but without the extended tips 32. In this way the inclined edges are not aligned vertically, but spaced transversely according to the amount that the tip of the tab is truncated. This provides further overlap of the vertically spaced tabs in a channel to provide increased turbulence by increasing the tortuous nature of the vertical path past the tab edges in a channel.

In Figs. 10-12, a further embodiment is illustrated.

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In this embodiment a packing structure 190 is fabricated from a sheet substrate of the same material as described above for the embodiments of Figs. 1 and 5. The structure 190 comprises a plurality of identical packing elements 192. A representative element 192 comprises square alternating channels 194, 194' in opposite facing directions as in the prior embodiments.

Vortex generator tabs 196, 198 and so on are in repetitive arrays and are in each channel. The tabs 196 and 198 are preferably identical in peripheral dimensions and are formed from a planar blank sheet of substrate material. The tabs are rectangular in plan view and

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inclined downwardly from the wall from which they are formed and depend. Tab 196 is formed from and extends from side wall 195. Tab 198 in channel 194 is formed from and extends from side wall 193.

The tabs have a width  $w$  preferably greater than one half the channel depth  $d$  so as to have a portion 204 which overly one another in the vertical direction along the channel length, Fig. 10.

The tabs 196 have an edge 200 adjacent to connecting wall 202. The tabs 196 have a distal edge 206. Tabs 198 have an edge 208 next adjacent to the connecting wall 207 of the adjacent element 209. The tabs 198 have a distal edge 210. Edges 210 and 206 are spaced from each other when viewed vertically to form portion 204.

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The tabs 196 and 198 form openings in the lateral side walls from which they are formed. Openings 211 are formed in the channel connecting walls 210 to provide fluid communication to the channels of adjacent elements such as elements 192 and 209.

It should be understood that the elements may include a greater number of channels and tabs than shown which are a relatively smaller portion of the packing array of elements. The pattern of the tabs may repeat in the manner shown or any other arrangement according to a particular implementation. Like the other embodiments, no linear vertical fluid path is present in any of the

channels. The overlapping tabs provide a tortuous vertical path for the fluids.

Although the invention has been described with respect to a specific structure, it is to be understood that the present invention is not limited to such structures.

The present invention has broad applicability to the use of mesh structures as a packing, with or without a catalyst, preferably with a catalyst wherein the operation of such packing is improved by providing the packing with turbulence generators. Such improvement is obtained in part by increasing liquid flow through the pores (openings) of the porous packing and in a preferred embodiment, the packing is provided with openings in addition to the pores in the packing, which openings are larger than the pores. Packing formed in this manner can be assembled into a wide variety of configurations.

The present invention has particular applicability to structured packing used in a catalytic distillation reactor wherein the structured packing includes a catalyst coating; for example, the fibers forming the mesh structure include a catalyst coating.

While particular embodiments have been described, it is intended that the described embodiments are given by way of illustration rather than limitation.

Modifications may be made by one of ordinary skill. The scope of the invention is defined in the appended claims.

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## WHAT IS CLAIMED IS:

## 1. A product comprising:

a structured packing for promoting contact between fluids, said structured packing comprising a porous material in which the average pore size is no greater than 50 microns, said porous material including turbulence generators to promote flow of liquid through the packing essentially over the entire surface of the packing.

2. The product of Claim 1 which includes additional openings through the packing which are larger than the pores.

3. The product of Claims 2 wherein said structured packing is formed from a plurality of metal fibers having a diameter of from 1 to 25 microns.

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4. The product of Claim 1 wherein said structured packing includes a catalyst coating.

5. The product of Claim 4 wherein said structured packing is formed from a plurality of metal fibers having a diameter of from 1 to 25 microns.

6. The product of Claim 5 wherein the structured packing includes additional openings which are larger than the pores.

7. The product of Claim 6 wherein the structured packing provides a plurality of flow channels.

8. An apparatus comprising:

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a catalytic distillation reactor and structured packing in said reactor, said structured packing comprising the product of Claim 4.

9. An apparatus comprising:

a catalytic distillation reactor and structured packing in said reactor, said structured packing comprising the product of Claim 5.

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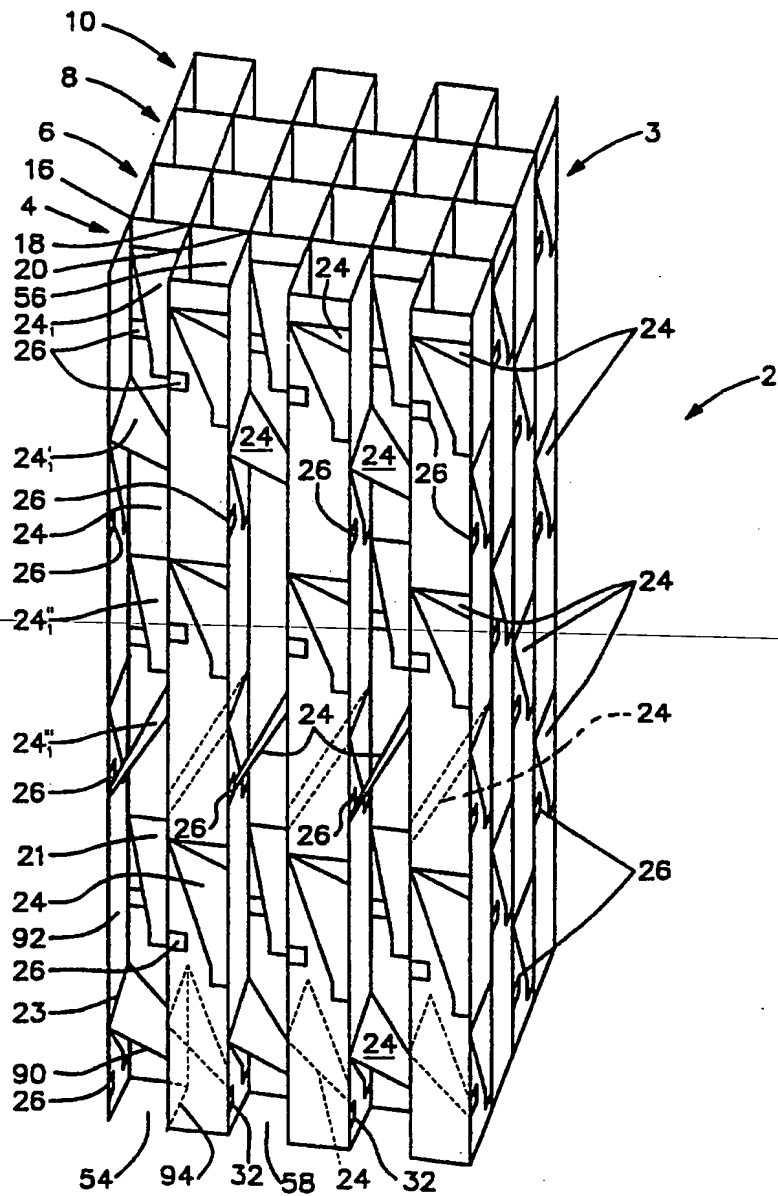
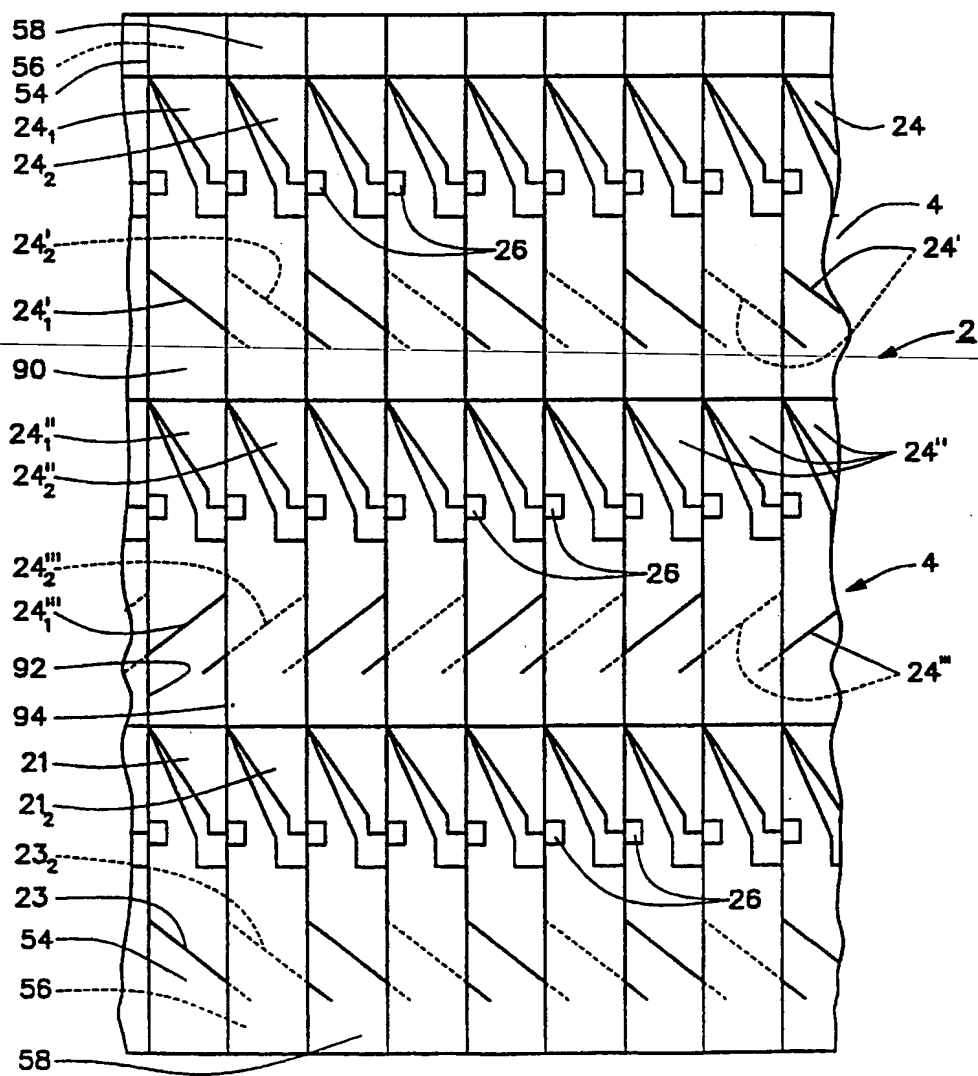
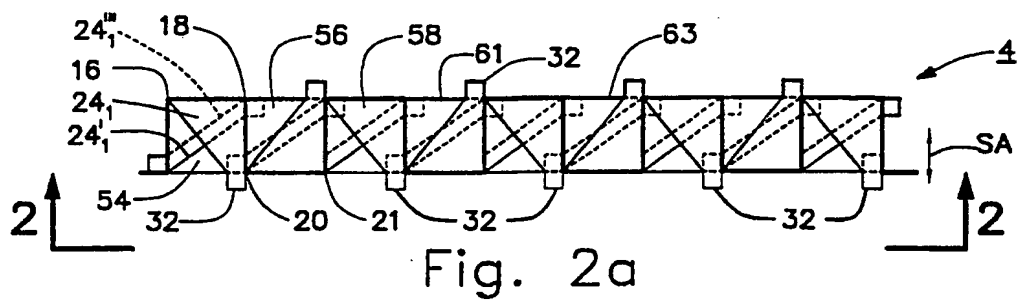


Fig. 1



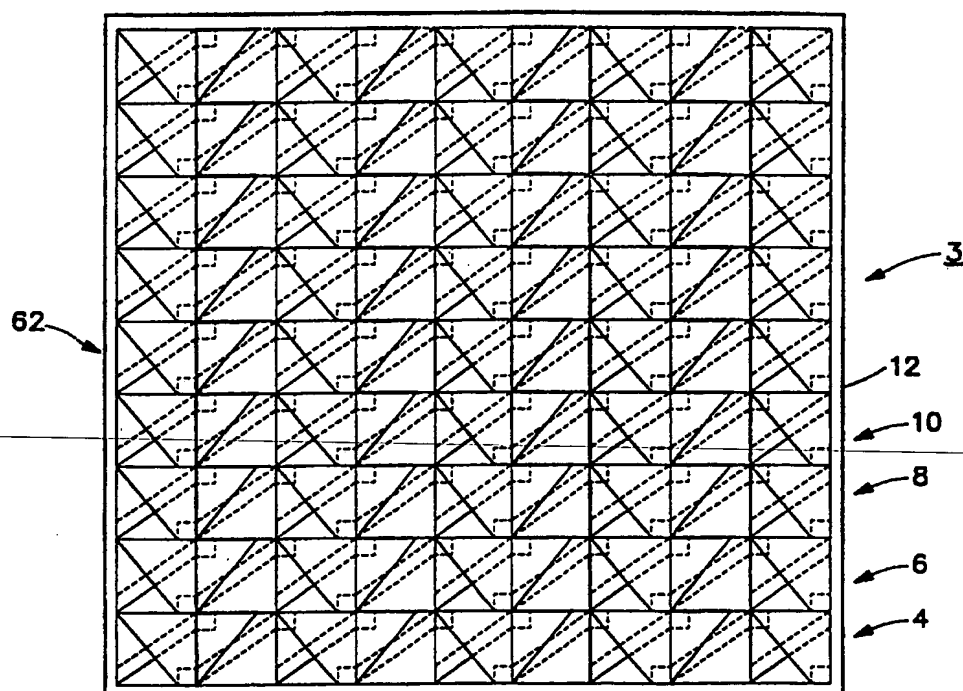


Fig. 3

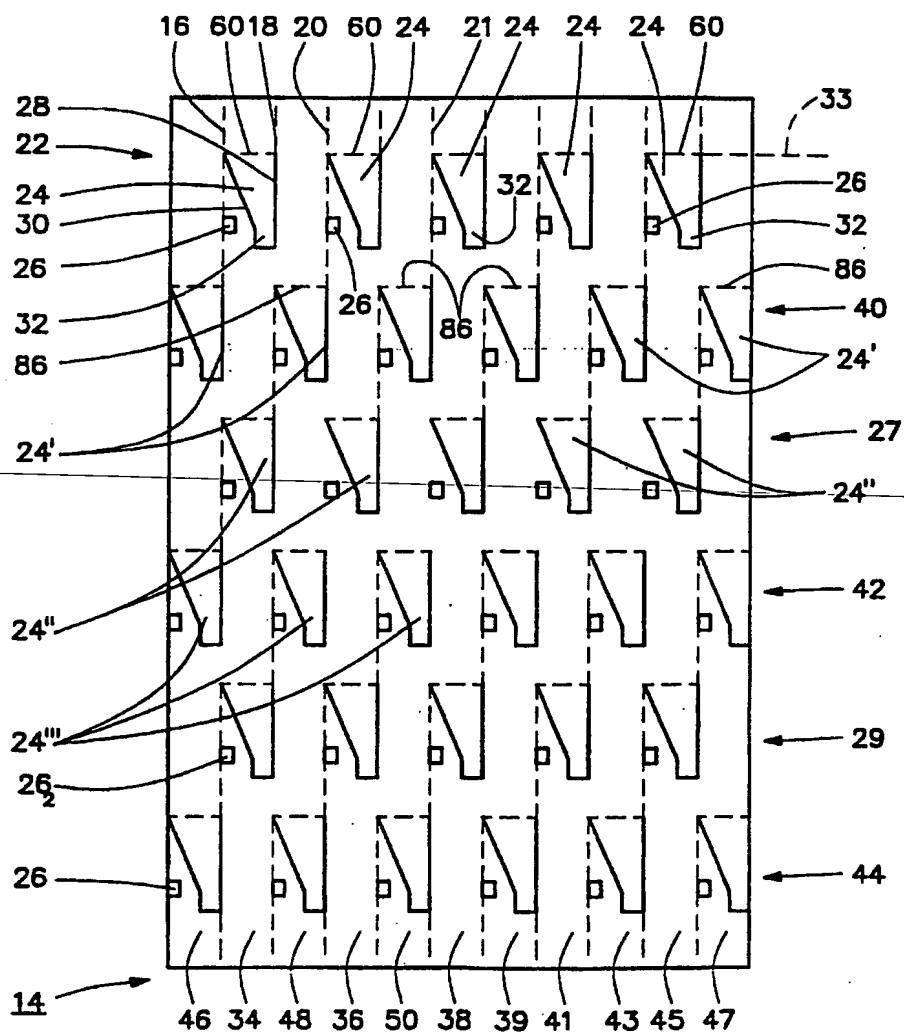


Fig. 4

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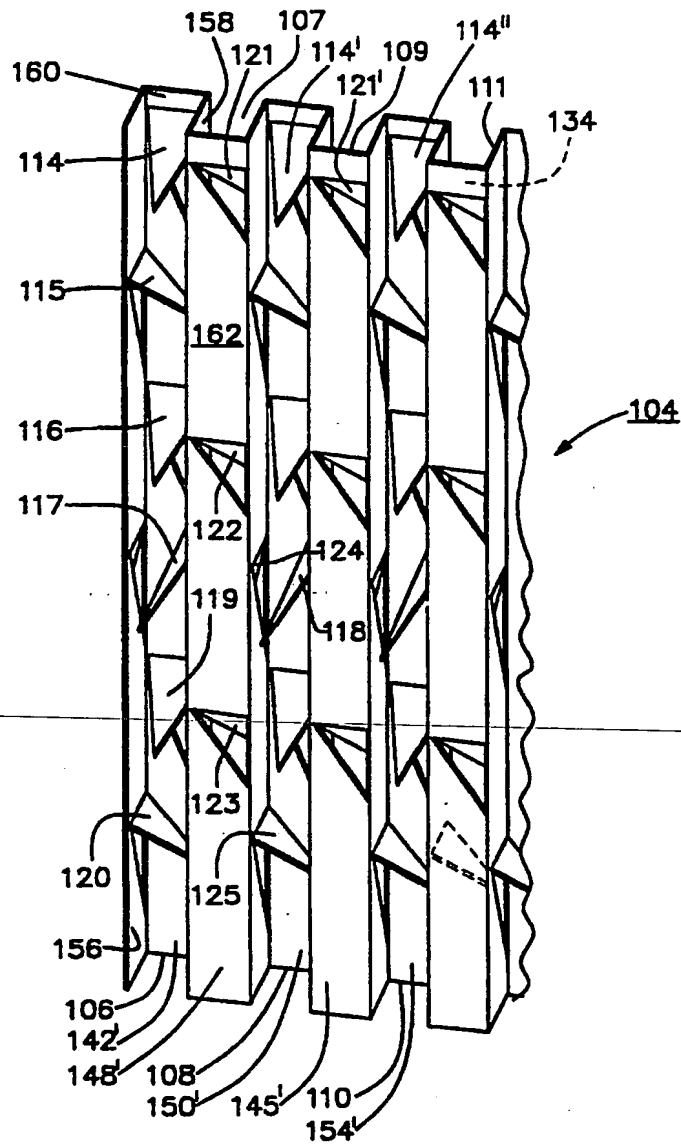
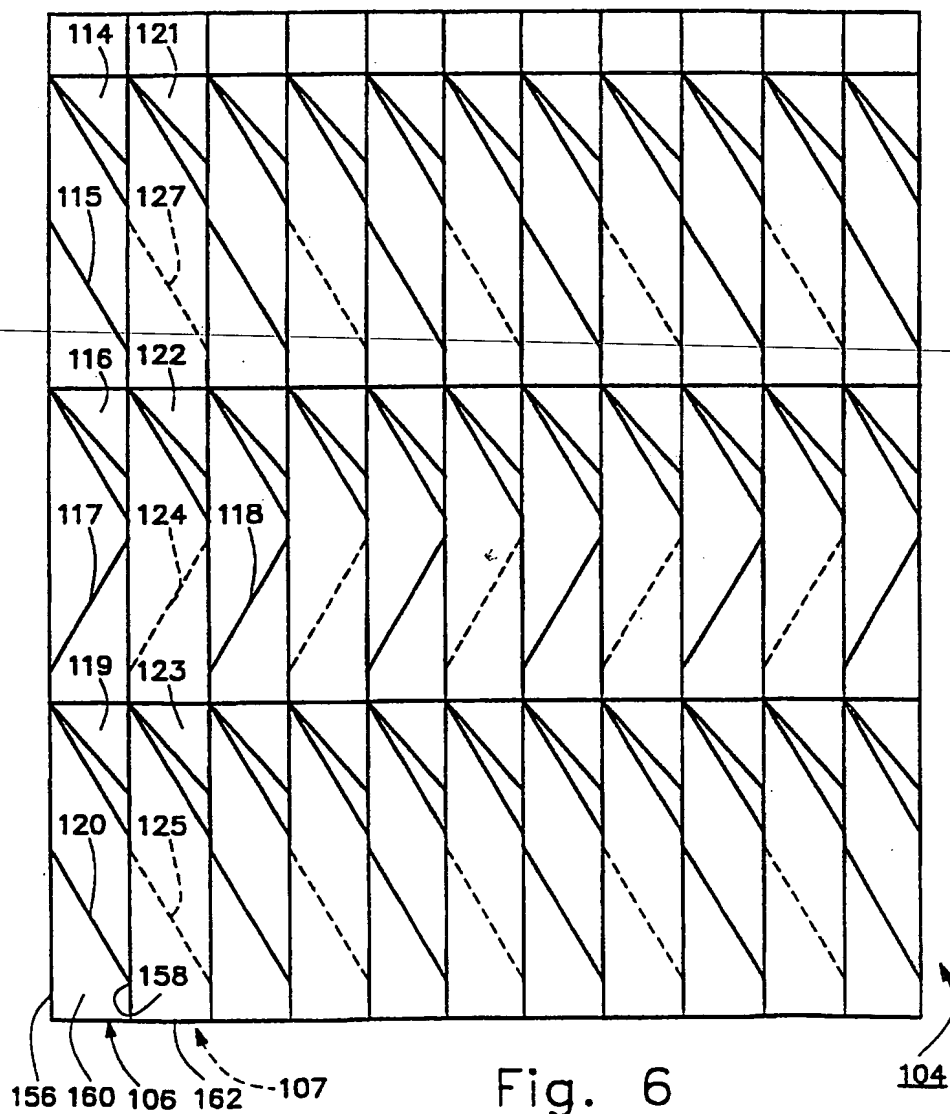
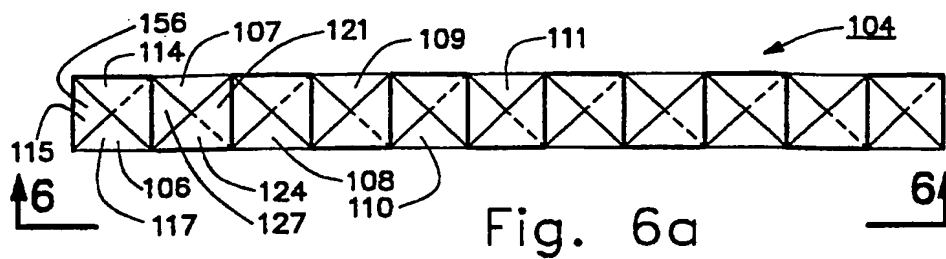


Fig. 5

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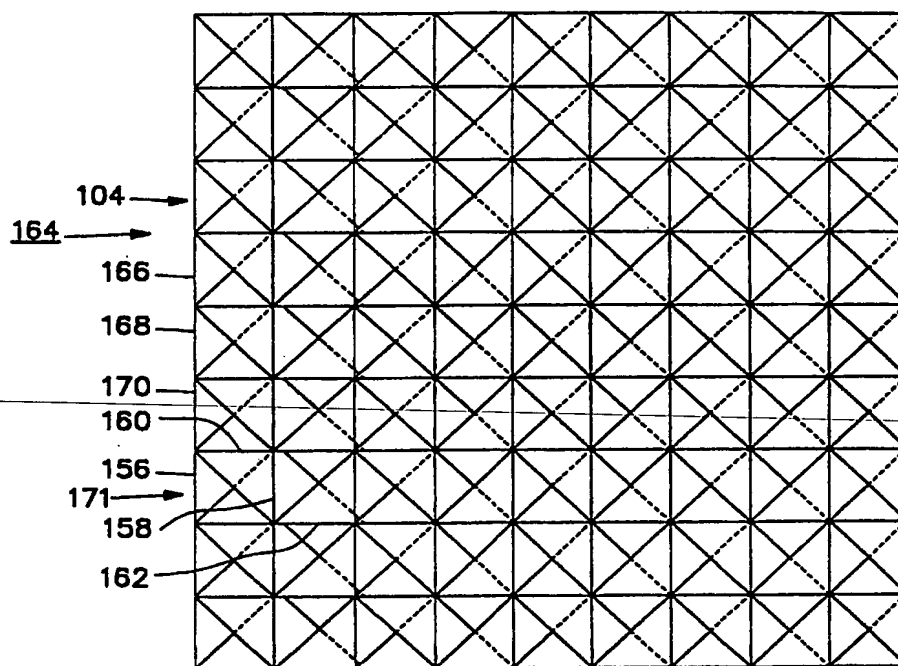


Fig. 7

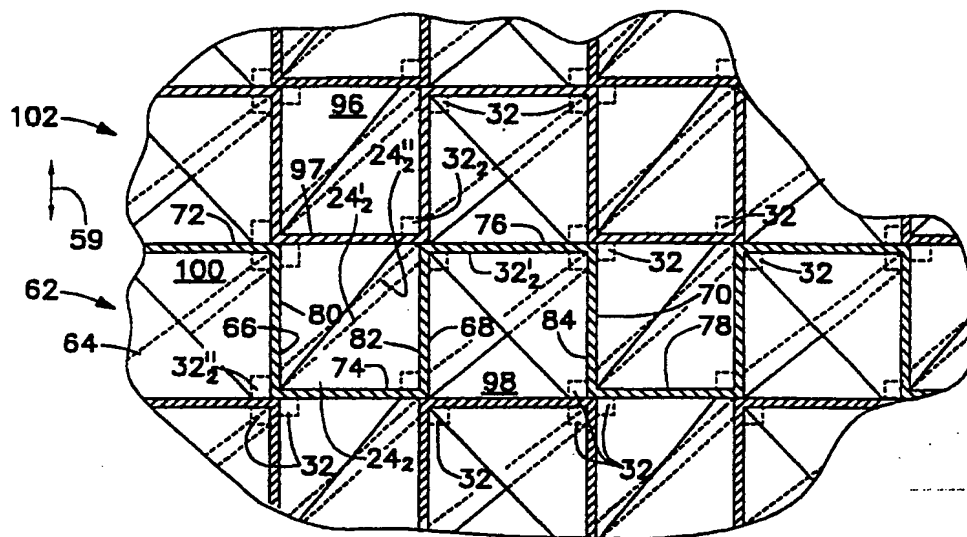


Fig. 3a

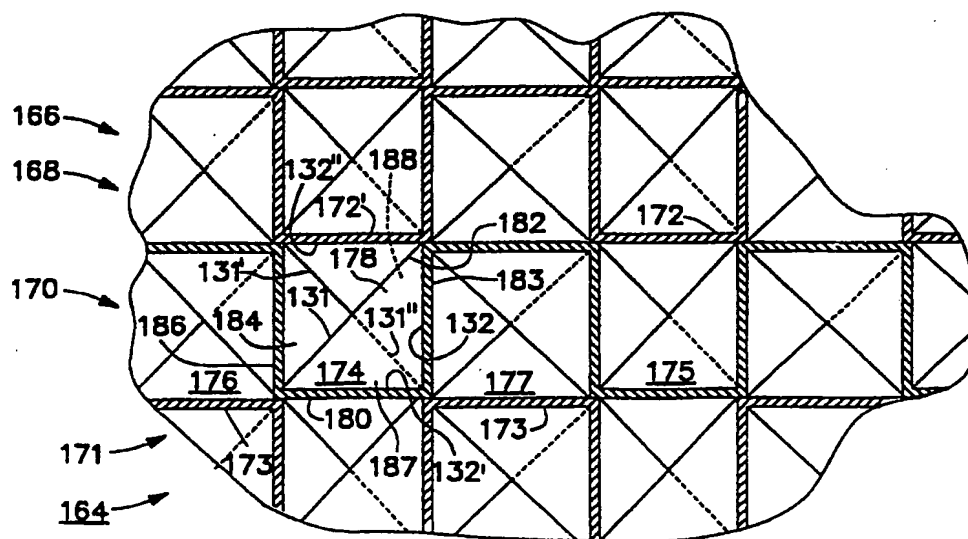


Fig. 8



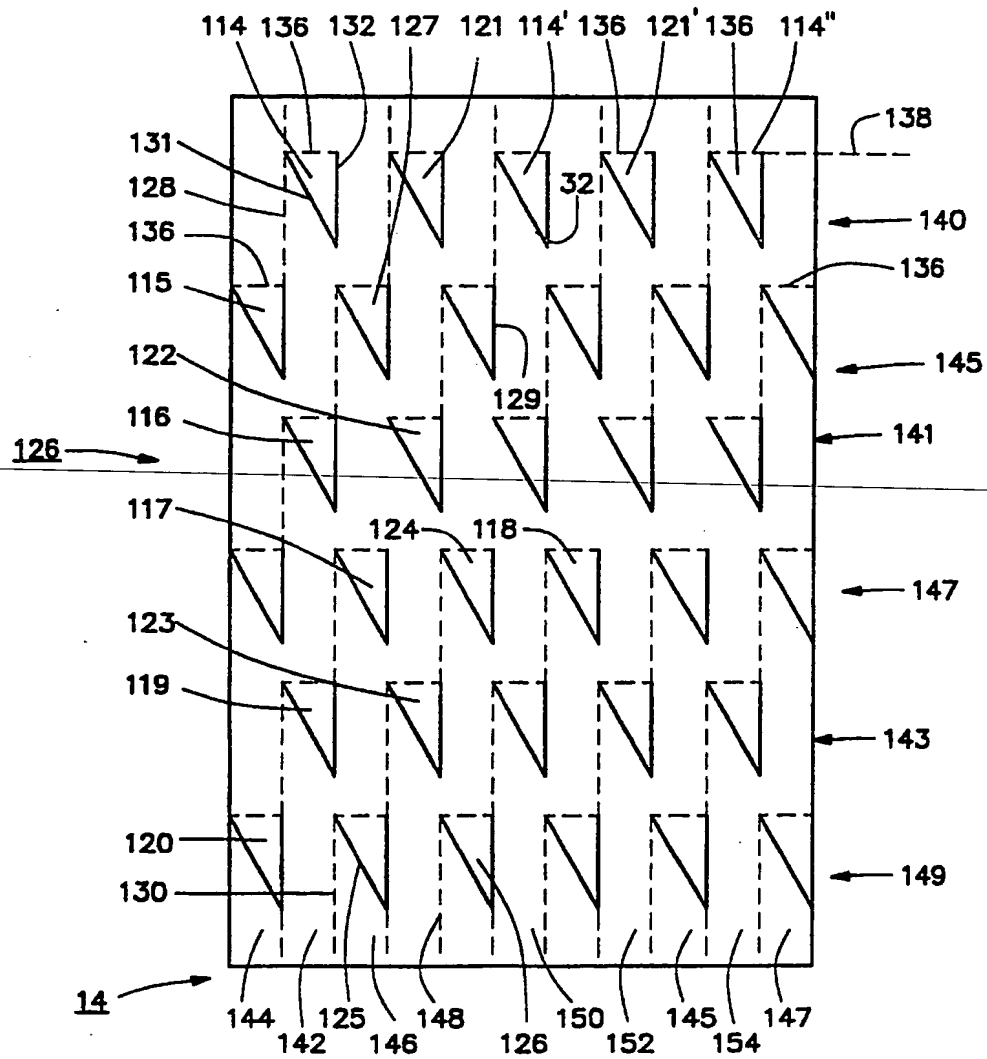
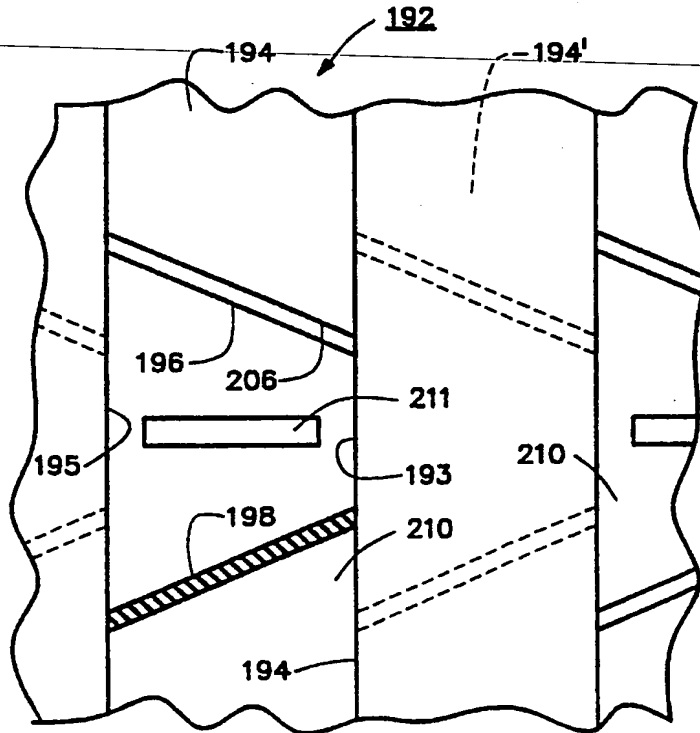
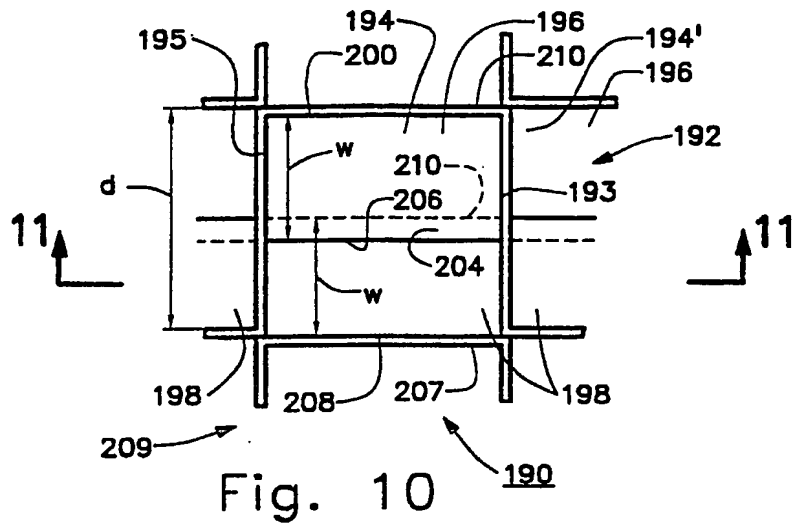


Fig. 9

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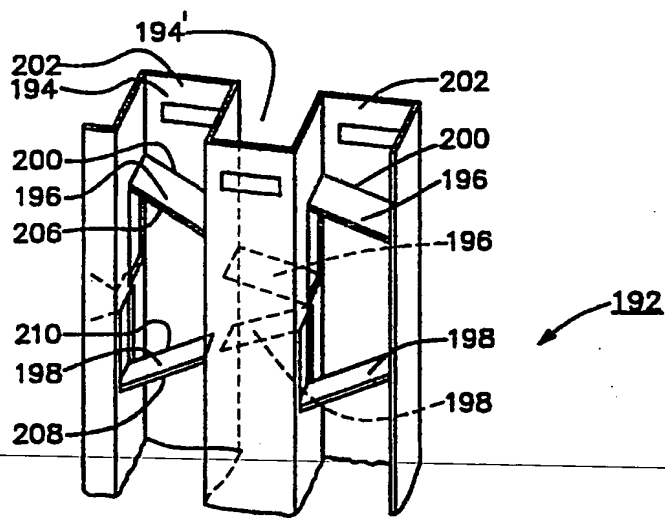


Fig. 12

# INTERNATIONAL SEARCH REPORT

Int. .tional Application No

PCT/US 99/10784

**A. CLASSIFICATION OF SUBJECT MATTER**  
 IPC 6 B01J19/32 B01D53/88

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 B01J B01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 902 418 A (ZIEGLER HEINRICH) 20 February 1990 (1990-02-20) column 4, line 44 - line 52 column 5, line 6 - line 26 claims 1-20; figures 11-13	1,2
X	EP 0 327 279 A (BOC GROUP PLC) 9 August 1989 (1989-08-09)	1,2
Y	claims 1-8	4,8
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A	page 6, line 4 - page 7, line 4	5-7,9

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

4 August 1999

Date of mailing of the international search report

13/08/1999

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Vlassis, M

# INTERNATIONAL SEARCH REPORT

Information on patent family members

Int. .tional Application No

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